

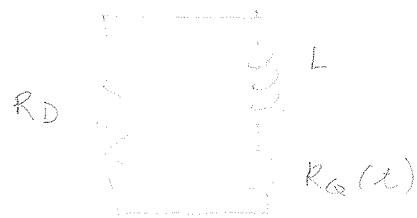
SSC DETECTOR SOLENOID DESIGN NOTE #18

TITLE: Quench Safety I: Choice of Current Densities
AUTHOR: R.W. Fast
DATE: Apr. 6, 1988

CONCLUSION

A 4-m coil module, with a conductor current density of ~ 3000 A/cm², will be safe against a quench and will have a sufficiently low surface heat flux. A 2-m module with ~ 5000 A/cm² will be safe on quench, but the surface heat flux is a bit high. A current density of 1600 to 1800 A/cm² will permit the coil modules, of whatever size, to be electrically connected into 8-m units.

I. Calculate the maximum current density that is consistent with quenching safely.



If we ignore the mutual inductance between coil modules and if $R_D \gg R_Q(x)$, the current decay is:

$$I(t) = I_0 e^{-\frac{R_D}{L} t} ; \quad J(x) = J_0 e^{-\frac{R_D}{L} x}$$

and

$$\int_0^L J^2(x) dx = \frac{1}{2} J_0^2 \frac{L}{R_D} = 27(\theta_m) \quad (\text{W/cm, p. 19})$$

Solving for J_0 :

$$J_0^2 = \frac{2 \cdot 27(\theta_m)}{L/R_D} ; \quad J_0 = \sqrt{\frac{2 \cdot 27(\theta_m)}{L/R_D}}$$

Now let $\theta_m = 100K$, with $R_{KB} \approx 100$,

($\rho_m = 10^{-10} \text{ } \Omega \cdot m$). then

$$27(\theta_m) = 7 \times 10^{16} \text{ } A^2 \cdot s \cdot m^{-4}$$

and

$$J_0(\theta_m = 100K) = \frac{3.74 \times 10^8}{\sqrt{L/R_D}} \text{ } A \cdot s^{1/2} \cdot m^{-2}$$

If we limit the terminal voltage to 500V

then

$R_D = 0.1 \text{ Oe}$ for a 5 kG magnet,
independent of L .

Solving for L (look for different combinations
of coil and core lengths):

Coil length inches	L^* (in)	R (Oe)	$L_{\text{core}}^* \text{ (in)}$ $\frac{L_{\text{core}}^*}{L^*} \text{ (in)}$
8	49.6	0.1	1679
4	18.1	0.1	2780
2	5.45	0.1	4932

* L for 9 in diameter; see (1) p 14.

II. Compare observed densities of various types of magnets

Magnet	Core (in)	Coil (in ²)	Observed R_D (Oe)
Wickert B.C.	4.9	6670	7
3341	2.8	9568	7
121 B.C.	11.5	3100	7
3347 B.C.	8.0	4075	200
1210 Super	8.0	3027	7
HFTE-Y.Y.	7.7	4978	210
HFTE-Solen.	5.2	4586	124

III. Suppose heat flux at $J_{\text{cond}} = 3000 \text{ A/cm}^2$
and $I = 5 \text{ kA}$ (a 4 m coil module)

$$A_{\text{cond}} \sim A_{\text{cu}} = \frac{5000}{3000} \text{ cm}^2 = 1.7 \text{ cm}^2$$

If the conductor were square, $a = b = 1.3 \text{ cm}$

$$\text{The heat flux} = \frac{I^2 \rho}{\gamma(ab) 2(a+b)}$$

where γ = fraction of surface wetted

Parameter	Normal	Normal Ext. Solen.	Normal Int. Solen.
Current (A)	2866	5000	5000
Conductor dimension (cm)	1.3 x 1.3	1.3 x 1.3	1.0 x 1.0
Area (cm ²)	0.625	1.7	1.0
Heat J (A/cm ²)	4586	3000	5000
ρ (ohm-cm)	10^{-8}	10^{-8}	10^{-8}
$\frac{I^2 \rho}{2ab(a+b)}$ W/cm ²	0.0225	0.0283	0.0325
$\frac{I^2 \rho}{\gamma ab(a+b)}$ W/cm ²	0.25	0.46	0.256
(pg 14, 16)			
γ	0.25	0.25	0.256

IV. Remarks

For a maximum hot-spot temperature of 100K, the conductor current density (3000 A/mm^2) is low in comparison with other cryostable magnets, but not absurdly so. The surface heat flux (0.0223 W/cm^2) is 25% less for a 9-m module than for HTF coils, again not absurd.

A more detailed quench analysis would require some information about the quench rate, the length of the quench, and the surface area of the coil. The surface area of the coil is not known.

V. Conclusion

A 9-m coil module, with a conductor current density of $\sim 3000 \text{ A/mm}^2$, will be safe against quench and will have a sufficiently low surface heat flux. A 9-m module with 25000 A/mm^2 will be safe in quench, but the surface heat flux is a bit high.